PIGGING OF PIPELINES WITH HIGH WAX CONTENT

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Abstract

The main purpose of this document is to provide guidelines for a best practice regarding pigging of pipelines with high wax content.

Introduction

Wax is a class of hydrocarbons that are natural constituents of any crude oil and most gas condensates. It is a sub-class of the saturated hydrocarbons and consists mainly of long-chain n-alkan with 20-50 carbon atoms, but may also contain minor quantities of branched and cyclic alkenes'. Wax is also defined operationally through its solubility in various solvents, most often ketone's like acetone.

Waxy oils may create problems in oil production due to three main reasons:

- Restricted flow due to reduced inner diameter in pipelines and increased wall roughness
- Increased viscosity of the oil
- Settling of wax in storage tanks

First, there is a potential for the wax to crystallize and adhere onto surfaces like the pipe wall in a pipeline and thereby form a deposit layer which will increase with time and eventually, in the worst case, completely block the line. Such deposition will reduce the capacity of the line by decreasing the effective diameter and increasing the wall roughness and thus the pressure drop in turbulent flow.

For any pipeline experiencing wax deposition, there has to be a wax control strategy. Most often, the wax control strategy simply consists of scraping the wax away from the pipe wall by regular pigging.

Sometimes, substantial quantities of wax are removed from the line. In one case, several tonnes of wax were collected in the pig trap at Statfjord B after pigging the line from Snorre B (Figure 1).

Secondly, wax precipitation causes the bulk viscosity of the oil to increase sharply and become shear-rate dependent (non-Newtonian), leading to increased pressure losses.

Ultimately, when a sufficient amount of solid wax has precipitated (approximately 4-6 wt%), the wax tends to form a three-dimensional network resulting in even larger viscosity increase ending up with a completely gelled structure with solid-like mechanical properties. Particularly during production shut-downs, when the oil is allowed to cool statically in the pipeline, this may be a severe situation, since high pressure may be required to break down the gel structure upon restart.

When performing regular pigging of a pipeline, the internal diameter is maintained as no/little wax deposit is allowed to build up. This will ensure an efficient flow.

Removal of debris, wax deposit, free water etc, ensure the pipelines is maintained according to Operator intention.

Wax precipitation

When oil is cooled down through the production system, wax starts to crystallize as a solid phase typically around 30 to 40°C. The onset of wax precipitation is referred to as the Wax Appearance Temperature (WAT) or cloud point. It is dependent on the wax content, the amount of solvents including dissolved gases, and to a smaller extent on the pressure as such.

The WAT is a very important design parameter in field developments, particularly subsea.

The solubility of wax is strongly dependent on temperature. In most oil reservoirs all wax is completely dissolved. There may be exceptions like some very shallow reservoirs. For instance, in the Pechora Sea (northern Russia) there are reservoir temperatures as low as 28-30°C. On the other hand, such reservoirs often contain biodegraded oil with low wax content.

Pigging for wax removal

There are several reasons for cleaning/pigging a pipeline regularly during operations. Some can be split up as follow:

- Improve Flow efficiency
- Remove debris, wax deposit, free water etc
- Clean pipeline for in-line inspection tool

Pig scraping is the most common wax control method whereby wax is allowed to deposit on the pipe wall and thereafter removed by passing a pig through the line at regular intervals. In the North Sea this is also widely used for pipelines with high wax content. Pigging frequencies may range from 2-3 days to 3-4 months.

For subsea pipelines requiring regular pigging, the pipelines should be configured in such a way as to allow round-trip pigging. This can either be achieved by installing dual lines of the same diameter or by utilizing a smaller diameter service line or, for instance, a water injection line for carrying the pig out to the template. Also, pigging platform to platform or platform to onshore is an easier way to perform pigging operation.

Research and engineering is still ongoing in order to come up with good design of flexible pigs allowing for variable pipeline diameters. Alternatively, subsea pig launching is now being implemented. Three pigs are then loaded at the same time and launched into the pipeline automatically, one by one.

There is a whole range of pig types ranging form huge metal scraper pigs, via brush types to small foam spheres.

In one of the North sea pipelines a sequence of pigs, starting with small foam spheres and ending up with large metal scrapers, had to be used in 1987 because wax had been allowed to build up to unmanageable thickness for a single pig. This is

a good example of how even a severely blocked line can be opened for full flow through a careful, though costly, operation.

A very important factor for efficient wax pigging is that the pig has a certain by-pass of liquid. This is achieved by having small by-pass holes in the pig allowing liquid to be 'flushed' through due to the pressure drop across the pig. The fast flow of liquid through the by-pass holes will help moving the wax in front of the pig away from the pig and disperse it in the oil. This is important since it reduces the chances that the pig gets stuck.

When performing regular pigging of a pipeline, the internal diameter is maintained as no/little wax deposit is allowed to build up. This will ensure that the flow efficiency is maintained.

Regular pigging of the pipelines also ensures removal of debris, wax deposit, free water etc, is maintained according to Operator intention.

Before a pipeline with high wax deposit is being pigged, a pigging program has to identify type and numbers of pigs. The use of a non suitable pig can, in the worst case lead to full pipeline blockage.

As the pig enters the pipeline, it removes the wax deposit of the pipewall and pushes the wax in front of the pig. As the pigging length increase, the volume of wax also increases in front of the pig.

The wax deposit can, depending on pipeline size, length and volume of wax, build up to a plug several hundred meters long.

During pigging, the wax deposit can build up in front of pig until the differential pressure required driving the pig equals the pigging pump pressure whereas a full pipeline blockage occur.

For example, pigging an 8” pipeline with a 12 mm layer of wax deposit can create a wax deposit “plug” 1 km long. The differential pressure to push this pig/plug can therefore be extremely high and in the worst case, not be possible, which ends up with a stuck pig in the pipeline.

By choosing the correct pig design and pigging frequency, this scenario can be avoided; hence the effectiveness of the pigs can be reduced. This will result in a pigging program where the cleaning operation has to be repeated more often than by using the most aggressive pig design.

In order to remove wax deposit from a pipeline, a pigging program has to be established. Type and amount of pigs depend on the estimated volume of wax deposit.

Cleaning pigs are generally designed to push any loose material through the pipeline and to apply a mechanical force between the pig and the pipe wall to remove debris. Cleaning pigs are available in all different size and types, delivered “from the shelf” or specifically designed for each pipeline. This can make it more difficult from an operator’s view on which types of pig to choose.

In the case illustrated in Figure 1, the pig used did not have by-pass. Hence, a large amount of wax (about 3 m^3!) accumulated ahead of the pig and entered the pig trap. Ideally, if the pig is designed correctly, no wax plug at all should arrive in the pig trap.

Figure 1 Part of a wax plug retrieved from the pig trap at Statfjord B after pigging the pipeline from Snorre B to Statfjord B (Sept. 2001)

It is very difficult to predict pigging frequency in advance, primarily because current wax deposition models are inherently uncertain with regard to predicting rate of deposition.

Pigging frequency has to be established by experience when the field is on production. It is recommended to start with relatively high frequent pigging. This is because of the danger of ending up with a pig stuck in the line if too much wax has to be removed. There is no clear criterion as to the thickness of wax allowed, but for example some Companies use 2 mm as a limit. This sounds little, but could build up to enormous amounts of wax over kilometres of pipeline.

Several pigs have become stuck during pigging operations due to amount of wax building up in front of pigs. This may be due to lack of information of wax appearance, wrong pig design or simply not taking into account the problems wax appearance can have on pigging operations.

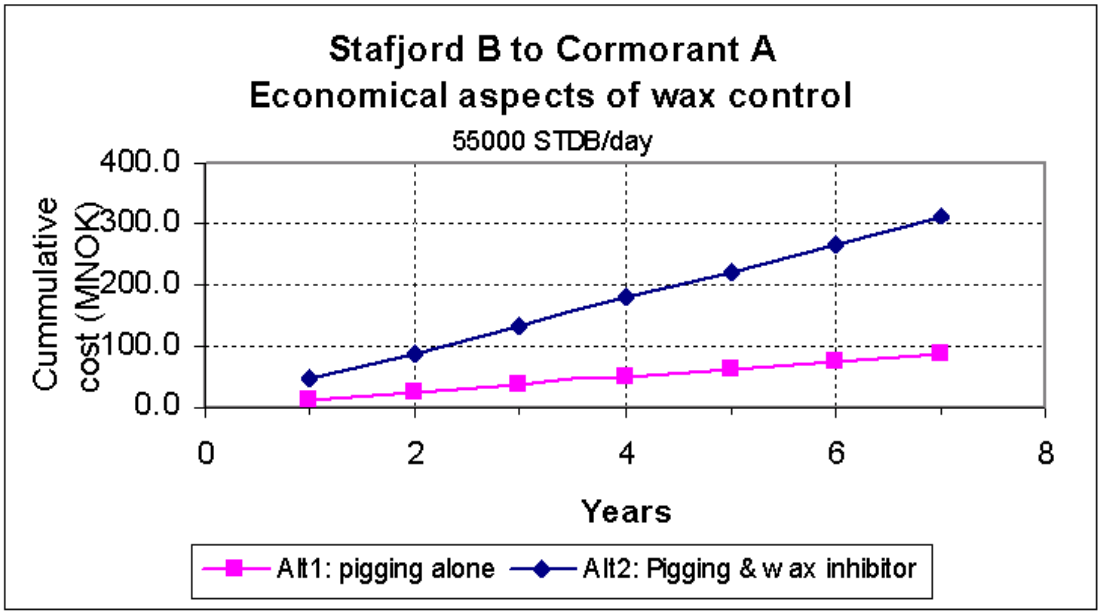
Pipeline Inspection

The cleanliness level of a pipeline is a concern when it comes to running ILI-tools, as these tools are expensive to hire and oil/gas production may have to be reduced to accommodate the maximum velocity of the in-line inspection tool.

When running ILI-tool in a pipeline with high wax content, the inspection may in worst case fail. This can be caused by sensor lift-off, the ability to accurately measure size and depths of any pits and wall thickness. Also the mechanical parts, such as odometer wheel, get packed in wax which can result in loosing all distance measurements data.

Pigging frequency - Wax inhibition

Most often, in oil pipelines which can easily be pigged (for instance between two installations), pigging will be the preferred wax control method. There may be a question whether wax inhibitor should be used to reduce the pigging frequency. A cost analysis of pigging alone vs. pigging combined with inhibition (figure below) shows that pigging alone will be far less expensive in this case.



Rules-of-thumb

- The wax appearance temperature of most "normal", paraffin North Sea oils and condensates is in the range 30° to 40°C.
- The wax appearance temperature tells whether there is going to be wax deposition in a pipeline and thus whether wax control measures have to be planned for.
- Dissolved gas always has the effect of lowering the wax appearance temperature - typically by 6-8°C for 100 bar increase of saturation pressure (bubble point).
- 100 bar increase of saturation pressure typically corresponds to increasing the content of C1-C5 components by 35-40 mole%.
- Pressure alone (at constant composition) always increases wax appearance temperature - typically by 2°C pr. 100 bar.
- Wax deposition rates will in general be much higher in un-insulated than insulated pipelines.
- Wax deposition seems in general to be less severe in multiphase systems containing free water and gas than in comparable single phase's systems.

- Wax inhibitors generally do not lower the wax appearance temperature significantly.

- In order for wax to be dissolved by hot flushing, the temperature should be at least 20°C higher than the wax appearance temperature.

- No more than about 2 mm of wax should be allowed to build up in a pipeline before it is pigged.

- Current wax inhibitors never totally prevent wax deposition, only reduce it. Wax inhibition therefore normally is a supplement to pigging or hot flushing in order to reduce intervention frequency.

- The cost of wax inhibitors typically is about 2,5 EURO pr. litre.

- Typical concentration of wax inhibitor is 50 to 500 ppm (volume).

- Wax inhibitors should be added at a temperature at least 10°C higher than the wax appearance temperature, preferentially as high as possible.

Pigging frequency always has to be established by experience when a field is on production.

Conclusion

Prior to any pigging operation of pipelines with high wax content it is important to know the properties of wax and the challenges it can create. Calculation of worst case scenario should be performed in order to estimate volume of wax in pipeline.

The amount of collected wax in the pig receiver is a bad measure of the amount of wax present in the pipeline since most of the wax is re-dispersed in the oil during pigging. Most often only a few kilograms of wax are collected in the receiver, hence false indication of total amount of wax in the pipeline.

It is important to find the best pig design in order to avoid pigs getting stuck.

Most often pressure measurements are used to test wax deposition simulators, both in the laboratory and in the field. The idea is of course that formation of a wax deposit layer causes the effective pipe diameter to be reduced. Both in laminar and turbulent flow, the pressure drop along a pipeline are inversely proportional to the square of the diameter. Moreover, the deposit layer is believed to have a higher roughness than the original steel surface.

In laminar flow there is no effect of pipe wall roughness on the pressure drop. However, in turbulent flow the pressure drop is highly influenced by the roughness, becoming larger the larger the roughness is. The effect becomes more significant the more turbulent the flow is (i.e. the higher the Reynolds number is). Whether the roughness really increases and by how much is uncertain, and is in fact one major problem when assessing the agreement between simulations and field data.